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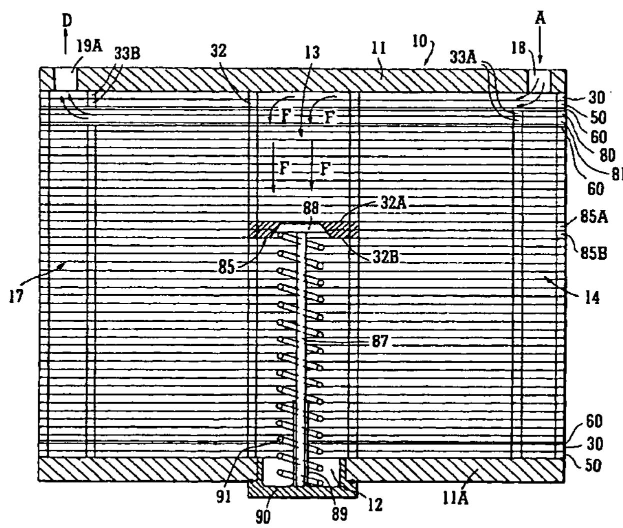

(57) Abstract: A heat exchanger in the form of a stack of plates (11, 11a, 30, 50, 60, 80, 81, 100) comprising a first group of generally annular plates (30, 50, 100) having a tortuous first flow path formed therein for a first fluid and a second group of generally annular plates (80, 81, 100) having a tortuous second flow path therein for a second fluid. A plate (60) is provided for separating the first and second fluids. The inner peripheries of the plates (11, 11a, 30, 50, 60, 80, 81, 100) defining a bore (31) through the stack. At least one of the flow paths is a radial flow path.

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HEAT EXCHANGER

This invention relates to a heat exchanger and particularly to a heat exchanger which is formed from a stack of plates bonded together.

The invention is particularly intended to provide a heat exchanger of a compact design having high "area density", i.e. having a high ratio of heat transfer surface to heat exchanger volume. Area density may typically be greater than $300m^2/m^3$ and may be more than $700m^2/m^3$.

The invention is also particularly intended to provide a heat exchanger which can be used to cool engine oil in aerospace and other applications where there is frequently a need to include a bypass valve in the construction whereby the oil may bypass the cooling effect of the heat exchanger until cooling is actually needed, i.e. to avoid overcooling of the oil and consequent poor oil circulation.

Oil is generally used as a lubricant for moving parts and in doing so takes in heat in the form of frictional energy and also as a consequence of being circulated under pressure by a pump. In order that the oil is maintained in an optimum condition to act as a lubricant its temperature must be controlled within quite close limits. Thus it must be cooled within a heat exchanger, which is frequently of the shell and tube type. The cooling medium used would typically be the actual reservoir of fuel that is used to power the engine.

When an aircraft engine, for example, is first started, both fuel and oil are cold and so initially the oil requires no cooling and in fact may remain in this condition for some time but both the oil and fuel are still circulating. Thus the oil needs to bypass the region being cooled

by the fuel until its temperature reaches a point at which cooling becomes beneficial. This can be arranged by incorporating a pressure relief and/or a thermal-pressure relief valve. Its purpose is to ensure that oil is forced to pass through the cooling section when the oil needs cooling, but to ensure that it does not do so when cooling would be detrimental. Savings in space and cost can be achieved if the valve or valves that control these functions are mounted adjacent to, or preferably integral with, the heat exchanger.

Conventionally, the body of the bypass valve may be part of a casting that would also include the shell or casing of the heat exchanger. Alternatively, the valve body may be a separate fabrication that is welded or brazed to the shell. Neither of these methods lend themselves to manufacture using diffusion bonding.

It is, therefore, an object of the present invention to provide a heat exchanger with an integrally-formed bypass valve, which heat exchanger can be manufactured by diffusion bonding or, e.g., furnace brazing.

Accordingly the invention provides a heat exchanger comprising a series of plates which are stacked and bonded together in fluid tight manner, the plates of the stack comprising an end plate at each end of the stack and alternate first and second groups of plates along the stack, the first and second groups providing flow paths for a first and second fluid respectively, the peripheries of the plates having integral, outwardly extending loops, the loops stacking together to provide inlet and outlet tanks for first and second fluids on the exterior of the stack, the tanks communicating with the flow paths of the groups of plates via an inlet and an outlet for the respective fluids into and out of their respective groups of plates, each group of first plates being separated by a solid plate from an adjacent second group of plates, each plate of the stack having a centrally disposed hole defined by an annular

surround, the aligned holes forming a bore through the stack, the flow path for each first group of plates being configured to flow from its inlet towards the annular surrounds of its plates and then to turn towards the outer peripheral edges of the plates at a position adjacent but spaced from the inlet and to continue with successive inward and outward flow around the group of plates until its respective outlet is reached, the annular surrounds of a first group of plates adjacent one end of the stack having one or more apertures leading into the central bore and the bore containing a movable valve member which in a first position prevents flow through the bore and in a second position provides a fluid bypass route through the bore.

In a preferred embodiment another first group of plates positioned adjacent the other end of the stack also has apertures in the annular surrounds of its plates. Thus first fluid, e.g. oil, when the valve member is in the first position, may flow into the first fluid inlet tank via an inlet at one end of the stack, fill the inlet tank on the outside of the stack, flow from the inlet tank across each group of first plates via their respective inlets, out through their respective outlets and finally out through an outlet at the opposite end of the tank. However, if the valve member is in the second position, the first fluid will pass from its stack inlet to fill the inlet tank and will preferentially flow across the first group of plates at the inlet end of the stack, pass through the apertures into the central bore and along the central bore to reach the first fluid outlet via the apertures in the annular surrounds of the plates at the other end of the stack. Thus the first fluid will not pass to any significant extent across intermediate first groups of plates in this mode and little or no heat exchange will take place.

The bypass valve may be a conventional valve arrangement. Thus the valve member may have a stem and valve seat, the latter co-operating with a corresponding seat defined in the central bore. The opening and closing of the bypass valve may be temperature and/or pressure controlled. It may be spring controlled and/or operated by mechanical linkage.

Where the heat exchanger is to be used to cool engine oil, as referred to above, the oil can circulate around alternate first groups of plates in the stack and the engine fuel can circulate around alternate second groups of plates sandwiching the first groups of plates containing the circulating oil. It will be appreciated that, as indicated above, it will normally only be necessary for the first and last first groups of plates in the stack to contain apertures in their annular surrounds to allow flow of oil, when required, into and then out of the central bore.

Conveniently, the flow paths of the second fluid through the second groups of plates may be similar to those of the first fluid, i.e. they may provide successive inward and outward flow as the paths travel around the plates from the inlet to the outlet of their respective groups. Flow of second fluid into the central bore will not be permitted.

Improved heat transfer between the two circulating fluids may be achieved by causing them to pass in opposite directions to each other as they pass around their respective groups of plates.

The plates of a group of plates may be provided with any convenient means to provide the desired inward and outward flow to circulate between the inlet and outlet of the group. Conveniently, the inlet and outlet will be side by side at the outer peripheral edge of the plates so that fluid circulation is completely around the plates.

In another preferred embodiment, the pair of plates are of the so-called "pin-fin" type, particularly as described in our co-pending international patent application number PCT/GB99/01622, publication number WO 99/66280. In that application is described a heat exchanger comprising a stack of parallel perforated plates, each plate of the stack having

perforations, characterised in that the perforations define an array of spaced column precursors, of thickness equal to the plate thickness, the column precursors being joined together by ligaments, each ligament extending between a pair of adjacent column precursors, the ligaments having a thickness less than the plate thickness, the column precursors of any one plate being coincident in the stack with the column precursors of any adjacent plate whereby the stack is provided with an array of individual columns, each column extending perpendicularly to the plane of the plates, whereby fluid flowing through the stack is forced to follow a tortuous flow path to flow around the columns.

Thus the plates of each first group and, if desired, of each second group used in the present invention may contain column precursors and ligaments as described in WO 99/66280, the column precursors of adjacent plates in a group stacking together to form the columns. Preferably the ligaments of each plate of the group are displaced relative to those of adjacent plate(s) in the group whereby fluid flowing across the group is not only forced to follow a tortuous flow path around the columns but also over and under each ligament. The column precursors may be arranged in sectors, each sector separated from the next by a barrier of thickness (height) equal to the plate thickness. Alternate barriers will extend one from the outer peripheral edge of its plate towards but not reaching the central annular surround and the next from the annular surround towards but not reaching the outer peripheral edge. The outer peripheral edge will itself form a barrier to flow, i.e. it will be of height equal to the plate thickness. By this means the groups of plates are divided into sectors, adjacent sectors being one for inward flow, the next for outward flow and so on. Flow of fluid can pass from the inlet towards the central annular surround and in the valve closed condition, pass around the inner end of the first barrier to flow to the outer peripheral edge, around the end of the second barrier, back towards the central annular surround and so on until the outlet is reached. Where the outlet and inlet lie side by side, the barrier

between their sectors of the plates will continue from the outer peripheral right up to the central annular surround to prevent flow continuing back into the inlet.

In an alternative embodiment the pairs of plates may have flow paths defined as described in our international patent application number PCT/GB98/01565, publication number WO 98/55812. In that application is described a heat exchanger comprising a bonded stack of plates, the stack comprising at least one group of main perforated plates, wherein at least two adjacent plates of the group of main perforated plates have their perforations aligned in rows with continuous ribs between adjacent rows and the adjacent plates are aligned whereby the rows of perforations in one plate overlap in the direction of the rows with the rows of perforations of an adjacent plate and the ribs of adjacent plates lie in correspondence with each other to provide discrete fluid channels extending across the plates, a channel corresponding to each row of perforations, the channels together forming one or more fluid passageways across the plates and the passageway(s) in the group of main perforated plates being separated from passageway(s) in any adjacent group of perforated plates by an intervening plate.

Thus the plates of each first group and, if desired, of each second group used in the present invention may be perforated plates having their perforations aligned in rows extending between the outer periphery and the central annular surround, the perforations, e.g. slots, of each row of one plate overlapping with those of an adjacent plate. Fluid may thereby flow across the group of plates in discrete fluid channels provided by the overlapping perforations and separated from adjacent channels by continuous ribs formed between the rows of perforations.

However, it is preferred that the plates be of the type having column precursors and ligaments as described in WO 99/66280. It will be appreciated that each sector of the plates of a group may need to be narrower nearer the centre than the periphery of the plates. In order, therefore, to prevent unwanted restrictions in the flow paths, which would cause undesirably high flow resistance, it is advisable to widen the spacings between any obstacles to flow as the centre of a plate is approached. This can more readily be achieved with the pin-fin type of arrangement as the column precursors can be formed of smaller diameter and/or their pitch or spacing can be increased as they near the central annular surround of a plate.

The plates may be of any conveniently shape in plan. Circular plan plates may be preferred but this is not essential and octagonal, hexagonal, square or any other desired, but preferably uniform, shape may be used.

The configuring of the plates to have any desired perforations, column precursors, ligaments, barriers and the like is preferably achieved by photochemically etching by known means although spark erosion, punching or any other suitable means may be used, if desired.

The plates of a stack are preferably of the same material and are preferably thin sheets of metal, e.g. of 0.5 mm thickness or less. The material may be stainless steel but other metals, e.g. aluminium, copper or titanium or alloys thereof, may be used.

As indicated above, the components of a stack may be bonded together by diffusion bonding or by brazing. Diffusion bonding, where possible may be preferred but, in the case of aluminium, which is difficult to diffusion bond, brazing may be necessary. It is then

preferable to clad the aluminium surfaces, e.g. by hot-roll pressure bonding with a suitable brazing alloy, in order to achieve satisfactory bonding by the brazing technique, although other means to provide the braze medium may be used, e.g. foil or vapour deposition.

The heat exchangers of the invention are not limited to use for the passage of two fluids only through the stack of plates. They may readily be adapted for multi-stream flows by the provision of appropriate extra inlet and outlet means on the exterior of the plates and the connection of those extra means to groups of plates dedicated to receiving a third, fourth and so on further fluid.

Multi-streaming may advantageously be used in different ways.

In a first instance, exemplified by an aerospace example, the coolant, e.g. the fuel, may be used to cool two different, separate oil streams, namely a lubricating oil and a hydraulic oil.

In another instance, again exemplified by an aerospace example, two different coolant streams may be used. Thus in addition to using the fuel as a coolant, cold air may also be used as a separate coolant stream. The cold air maybe used to cool either or both of the oil and fuel streams, i.e. as the fuel is gradually used up, its temperature may rise and hence it may need cooling.

In another instance a third or further fluid streams may be introduced with a view to injecting one or more fluids into a process fluid. Thus, for example, the first fluid may be a process fluid to be reacted with a third fluid and the second fluid may be a coolant or may provide heat depending on whether the desired reaction is exothermic or endothermic. The

injection of the third fluid into the second fluid may conveniently be achieved by replacing the solid plate between adjacent first and third groups of plates by a plate having injection holes through its thickness. The number, position and size of the holes can readily be determined by the skilled man of the art to achieve the desired injection rate and the third fluid will, of course, need to be circulated into the stack at the higher pressure than the first fluid to achieve the desired flow through the injection holes.

Thus in this latter instance, the heat exchanger of the invention may be used as a chemical reactor.

Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 is a perspective view of one form of heat exchanger of the invention;

Figure 2 is a plan view of a first plate for use in a first group of plates;

Figure 3 is a plan view of another plate for use in a first group of plates;

Figure 4 is a plan view of the plates of Figures 2 and 3 stacked together to form a first group of plates.

Figure 5 is a plan view of a solid intervening plate used to separate a first group of plates from an adjacent group of plates;

Figure 6 is an enlarged view of a portion of the plate of Figure 2;

Figure 7 is a diagrammatic illustration not to scale of a portion of a group of plates stacked together;

Figure 8 is a section through the heat exchanger of Figure 1 taken along a line corresponding to line VIII-VIII of Figure 1 and showing a bypass valve in closed configuration;

Figure 9 is a similar section to Figure 8 but corresponding to line IX-IX of Figure 1, again with the bypass valve in closed configuration;

Figure 10 is a similar section to Figure 8 but showing the bypass valve in open configuration; and

Figure 11 is a plan view of a different plate for use in a first group of plates.

In Figure 1 is shown a heat exchanger 10 formed from a bonded stack of plates. At the top of the stack is an end plate 11 which closes the top of the stack. The exterior of the heat exchanger has four integrally formed tanks 14, 15, 16 and 17 which are formed from the stacking of integrally formed loops on the outer peripheries of the plates of the stack. The four tanks provide inlet and outlet means for a first and second fluid. In this embodiment tank 14 is an inlet tank for a first fluid flowing in the direction of arrow A via hole 18 in top end plate 11, tank 15 is an outlet tank for first fluid flowing in the direction of arrow B via a corresponding hole 18A (see Figure 9) in a bottom end plate of the stack. Although not visible in Figure 1, the bottom end plate 11A is of similar structure to top end plate 11 except that it has a central hole 12 which is closed by a plug 90 (see Figures 8, 9 and 10). Tank 16 is an inlet tank for a second fluid flowing in the direction of arrow C via a hole 19 (see Figure 9) in the bottom end plate and tank 17 is an outlet tank for second fluid flowing in the

direction of arrow D via a hole 19A in top plate 11. The first and second fluids are circulated in opposite directions through the stack to improve heat transfer.

It will also be noted that the stack is formed with six longitudinally extending external columns 20, diametrically opposed in pairs across the stack. Each column has a through bore 21 to receive bolts whereby the heat exchanger may be bolted in its position for use. The columns and their bores are formed by corresponding extensions on each plate of the stack as is further described below.

In Figure 2 is shown one of two plates of a first group of plates. This group of plates lies immediately beneath end plate 11 in the stack. Plate 30 of Figure 2 has a central hole 31 defined by an annular surround 32. Its outer periphery 33 has an inlet extension loop 34 which in the stack forms part of tank 14 and an outlet loop 35 which forms part of tank 15. It also has extension loops 36 and 37 which form respectively pairs of tanks 16 and 17. It will be noted that loops 34 and 35 open into inlet sector 38 and outlet sector 39 respectively of the plate whereby first fluid may flow in to sector 38 from tank 14 and out of sector 39 into tank 15. In contrast loops 36 and 37 are separated from their respective sectors 40 and 41 of the plate by a continuation 33A of peripheral rim 33 so that second fluid cannot flow across this first group plate.

Central hole 31 is coaxial with central holes in all the plates below plate 30, thereby forming a bore 13 (see Figures 8 and 9) through the stack (other than through top plate 11) for the purpose of a bypass valve as is described in greater detail below.

Plate 30 has six peripheral lugs 42 each with a central hole 43. The lugs and holes stack together with similarly positioned lugs and holes in the other plates of the stack to form columns 21 with bores 22.

Between its outer peripheral rim 33 and its central annular surround 32, plate 30 is divided into sixteen sectors of which sector 38 and 39 are diametrically opposed to sectors 41 and 40. (It will be appreciated that more or less sectors may be used and the positions of the inlet and outlet sectors may be varied.). Adjacent sectors are separated by radially extending barriers 44, 45 which alternate around the plate. Barriers 44 extend radially inwardly from rim 33 towards but do not reach annular surround 32. Barriers 45 extend radially outwardly from annular surround 32 but do not reach peripheral rim 33. The rim barriers and central surround have a height equal to the plate thickness. By this means first fluid flow from tank 14 enters into inlet sector 38 and then flows around the plate in the direction of arrows E to reach outlet sector 39. Barrier 46 between sectors 38 and 39 extends completely from the peripheral rim to the annular surround so that fluid cannot pass directly between the inlet and outlet sectors. The fluid, therefore, exits into tank 15.

Each sector of the plate has a pin-fin construction with column precursors 47 separated by ligaments 48 of reduced thickness. For convenience the pin-fin construction is only illustrated in two sectors. It will be noted that the column precursors do not extend into the tank areas inside the loops 34, 35, 36 and 37, although, necessarily, the ligaments do extend across tank areas 34A and 35A to attach to the rim 33, this being shown inside loop 34 only.

Central annular surround 32 is provided with holes 49 which communicate with hole 31, i.e. they provide fluid communication into the central bore 13 of the stack. Only three

such holes are shown by way of an example adjacent inlet sector 38 but, if necessary, more may be provided around the surround 32 in other sectors. These holes 49 enable the desired bypass valve operation which will be described in greater detail below with reference to Figures 8, 9 and 10.

Figure 3 shows a plate 50 which is similar in construction to plate 30 and like parts have, therefore, been given the same reference numerals and need not be described again in detail here. The difference between plates 30 and 50 is in their pin-fin arrangement. Column precursors 47A in plate 50 are positioned to correspond to column precursors 47 in plate 30 so that, when the two plates are stacked together, the column precursors stack together in pairs to form columns 47B. (See Figure 4).

The ligaments 48A of plate 50 are, however, out of alignment with those 48 of plate 30. Again, when the plates 30 and 50 are stacked together, the overlapping of the ligaments 48, 48A can be seen in Figure 4.

First fluid flow around the first group of plates 30, 50 in the general direction of arrows E has, therefore, induced turbulence by the need to flow around the obstructions caused by columns 47B and the need to flow over and under the staggered ligaments 48, 48A.

A larger scale arrangement of column precursors and ligaments is described below with reference to Figure 7.

The first group of plates 30, 50 is separated in the stack from an adjacent second group of plates by a solid intervening plate 60 shown in Figure 5. Plate 60 has a central hole 61 to form part of bore 13 of the stack, six lugs 62 with holes 63 to line up in the stack to form

and 17. Between its rim 63 and its central hole 61, the plate 60 has a completely imperforate region 68 to prevent any mixing of fluids passing through a first group of plates on one face of it and through a second group of plates on its other face.

In Figure 6 is shown in enlarged scale a central part of plate 30 of Figure 2. The portion of central annular surround 32 containing holes 49 can be seen. Flow of first fluid in the direction of arrows F can take place into hole 31 of the plate, and hence through the central bore 13 of the stack, when the bypass valve, to be described in greater detail below, is in the open configuration. Also shown in this enlarged view are barriers 44 and 46 and column precursors 47 arranged in rows, adjacent pairs in each row being connected by ligaments 48. As shown, the ligaments are of width equal to the diameters of the column precursors. However, this is not essential and the ligaments may be wider or narrower as desired.

Figure 7 shows a portion of a group of four plates 70, 71, 72, 73. (It will be appreciated that the groups of plates may contain two or a greater number of plates as desired.) Each plate has a number of rows of column precursors 74, adjacent pairs of column precursors being joined together by a ligament 75. Each column precursor can be considered to extend for the full thickness of its plate and this is indicated in the right hand row of column precursors where their continuation through the thickness of their plates is shown by dotted lines. The column precursors of adjacent plates, therefore, stack together to form columns which cause turbulence in the fluid flow and provide heat transfer paths to the solid plates 60, described with reference to Figure 8 below, and also mechanical strength to resist internal pressure loads. The ligaments being of lesser thickness than the plate thickness allow fluid flow above and beneath them to allow the flow path, with turbulence, to pass around the sectors of a plate.

In Figures 8, 9 and 10 are shown sections through the heat exchanger 10 of Figure 1 with a bypass relief valve positioned in the central bore 13 in the valve closed position.

The stack of plates has a top plate 11 immediately underneath which lie plates 30 and 50 of Figures 2 and 3 respectively. Underneath plate 50 is a solid plate 60 to separate first fluid flowing around plates 30, 50 from second fluid flowing around the next pair of plates 80, 81, which form a second group of plates for a second fluid. Beneath plate 81 is another solid plate 60 and this pattern is repeated down the stack with another first group of at least two plates followed by a solid plate followed by another second group of plates and so on until the lowermost first group of plates 30, 50 is reached immediately above lower end plate 11A.

The plates of the second groups of plates may be of any appropriate configuration to provide flow channels for the second fluid. They may be similar to plates 30 and 50 but with the following differences. Firstly, the second group plates will not have holes 49 in central annular surrounds 32 as second fluid must not pass into the central bore 13 of the stack. Secondly loops 36 and 37 must open into their respective sectors 40 and 41 by removal of the portion 33A of rim 33 that is closing them off from those sectors in plates 30 and 50. Thirdly, loops 34 and 35, which in plates 30 and 50 open into their respective sectors 38 and 39 must be closed off from those sectors by appropriate extensions of rim 33. In other words the configurations of loops 34 and 35 on the one hand and loops 36 and 37 on the other hand must be exchanged. Finally barrier 46 of plates 30, 50 must be shortened to become a barrier 45 and barrier 45 between sectors 40 and 41 must be extended to become a barrier 46. By this means second fluid can flow from external tank 16 into sector 40 and around a second group of plates until it exits from sector 41 into tank 17.

The plates of the first groups in the stack, other than in the uppermost and lowermost first groups also need modification from plates 30 and 50. They may be identical to plates 30, 50 except in the provision of holes 49 in central annular surround 32. It is not wished in this embodiment of the invention that first fluid can flow into and out of the central bore 13 except via the uppermost and lowermost first groups of plates respectively. Plates of other, intermediate first groups, therefore, have central annular surrounds that are unperforated.

A bypass valve is fitted into central bore 13. It has a valve seat 85 positioned in the upper half of the bore and defining a tapering central hole 86 (Figure 10). A valve stem 87 with a head 88 shaped to close the hole 86 extends in the bore 13. The stem is telescopic and can slide in and out of a hollow lower stem base 89 which is integral with plug 90 which closes the lower end of bore 13. The stem is normally held in its extended position closing hole 86, and hence closing bore 13, by means of a spring 91.

Valve seat 85 may be formed by any convenient means. It could be a separate fitting, bonded into place in bore 13 preferably at the time of bonding of the stack. However, it is preferred to be integrally formed by appropriate sizing of the central holes in the group or groups of plates at the position in the stack where the valve seal is required. Thus, as is shown in Figures 8, 9 and 10, plates 85A and 85B have central annular surrounds 32A, 32B respectively that define smaller holes than holes 31 of the other plates. Surround 32A defines a smaller central hole than surround 32B and the inner edges of the surrounds are chamfered to produce the tapered valve seat 85. However, in practice it may be found that in order to achieve a satisfactory valve seat, it is necessary to use more than the thicknesses of two plates to provide the seat. Moreover, rather than forming the tapered hole 86 by tapering of the edges of the central holes of the plates during etching or otherwise forming of the holes, it is preferred to form the plates in the seat region with a smaller central hole and

then to machine the required hole size and edge shape through the hole 12 and bore 13 in the bonded stack.

The valve seat may be located at any convenient position along the bore. The skilled man will readily choose a position for his requirements taking into consideration factors such as the length of spring 91 and the head of first fluid that may gather above the valve seat in the valve closed position. (Of course, if the bonded stack is used upside down to the position shown in Figures 8 , 9 and 10, any first fluid between its inlet and the valve seat will drain downwardly rather than remaining as still fluid until the valve opens.).

In the valve closed position, shown in Figures 8 and 9, first fluid enters the stack at inlet 13, see arrow A, and fills tank 14. From sectors 38 of first plates 30 and 50 at the top of the stack it can flow into bore 13 via holes 49 in the central annular surrounds of those plates, again as indicted by arrows F. However, as the valve is closed, first fluid cannot flow further down bore 13. First fluid travel through the stack, therefore, in the valve closed position is around each successive pair of first plates 30 and 50 along the stack, the fluid travelling from their plate inlet sectors 38 to their outlet sectors 39 to leave via tank 15 and outlet 18A, see arrow B, in the lowermost pair of plates. In tanks 14 and 15 first fluid bypasses each pair of second plates 80, 81 because the loop extensions in the second plates will have peripheral rim extensions 33A in the sectors where they form part of the first fluid tanks 14 and 15.

Second fluid enters the stack at inlet 19, see arrow C, and while filling inlet tank 16 it similarly travels around each pair of plates 80, 81 from their inlet sectors 40 to their outlet sectors 41, in which rim extensions 33A are removed, to reach outlet tank 17 and then outlet 19A, see arrow D. Second fluid in tanks 16 and 17 bypass each pair of first plates 30, 50

Second fluid enters the stack at inlet 19, see arrow C, and while filling inlet tank 16 it similarly travels around each pair of plates 80, 81 from their inlet sectors 40 to their outlet sectors 41, in which rim extensions 33A are removed, to reach outlet tank 17 and then outlet 19A, see arrow D. Second fluid in tanks 16 and 17 bypass each pair of first plates 30, 50 because the loop extensions of the first plates in the sectors where they form part of the second fluid tanks have peripheral rim extensions 33B.

The bypass valve open position is shown in Figure 10. Second fluid flow is the same as in the closed position and so is not repeated here other than to show it entering at inlet 19 – arrow C. First fluid again enters at inlet 18 as shown in Figure 8 to fill tank 14 but will now preferentially flow into bore 13, see arrows F, and through the bore to its lower end. As that end is sealed by plug 90, the first fluid travels via holes 49 in the lowermost plates 30,50 and passes around those plates to reach outlet 18A, see arrow B.

The bypass valve is held in the closed position during normal operating conditions by compression spring 91. However, at start up of the engine with which the heat exchanger is used, the oil being cold is pumped at higher than normal pressure. This pressure forces the valve head 88 away from its seat 85 by compression of the spring 91, thereby allowing the oil to pass centrally down the bore 13 to its lower end. As the oil warms up, the pressure reduces and the spring will close the valve, thereby preventing the warmer oil from avoiding its alternative cooling passage through the heat exchanger.

In Figure 11 is shown another plate that can be used in a first group of plates and, if desired, in a second group of plates. The plate 100 is generally square in plan but for the extension loops which form the desired inlet and outlet tanks.

periphery also has two closed loops 106, 107 which are cut off from their respective sectors 110 and 111 by perimeter extensions 113A.

Inlet and outlet sectors 108, 109 are separated by a radial barrier 114 which extends up to annular surround 102. The other sectors of the plate, eight being shown in total, are separated alternatively by barriers 115 that extend from periphery 103 towards, but do not reach, annular surround 102 and by barriers 116 that extend from annular surround 102 towards, but do not reach, periphery 103.

Thus it can be seen that the plate can be used in a pair with a similar plate to form a group of plates that operates similarly to those described with reference to Figures 2, 3 and 4. Fluid flow across and around a pair of the plates can, therefore, proceed from inlet to outlet as indicated by arrows G.

It will be appreciated that each plate of this notional pair may have a pin-fin arrangement, which is only indicated generally by numeral 120 in Figure 11 and is shown in two sectors only although it will, of course, be formed in each sector. The ligaments of the pair of plates will be offset from each other as discussed above to provide flow with turbulence.

CLAIMS

1. A heat exchanger in the form of a stack of plates (11, 11a, 30, 50, 60, 80, 81, 100) the stack comprising a first group of generally annular plates (30, 50, 100) having a tortuous first flow path formed therein for a first fluid and a second group of generally annular plates (80, 81, 100) having a tortuous second flow path therein for a second fluid, means (60) for separating the first and second fluids, the inner peripheries of the plates (11, 11a, 30, 50, 60, 80, 81, 100) defining a bore (31) through the stack, and at least one of the flow paths being a radial flow path.

2. A heat exchanger according to Claim 1, wherein a first one of said radial flow paths is a radial flow path and communicates with said bore (31) whereby said first radial flow path is at least partially bypassed (49) by said bore (31) bypass valve means (85, 87, 89) being arranged to control bypass flow through said bore (31).

3. A heat exchanger according to Claim 2, wherein said bypass valve means (85, 87, 89) comprises an axially movable stem (87) aligned with said bore and carrying a head (88) which co-operates with a seat (85) defined in said bore (31).

4. A heat exchanger according to Claim 2, wherein said bypass valve means (85, 87, 89) is arranged to be temperature and/or pressure-controlled.

5. A heat exchanger according to any of Claims 2 to 4, wherein said bypass valve means (85, 87, 89) is spring-controlled (91).

6. A heat exchanger according to any preceding claim, wherein said flow paths are defined by perforations in said generally annular plates.

7. A heat exchanger according to any of Claims 1 to 5, wherein said flow paths are defined by the gaps between pins (47, 47a) carried on ligaments (48, 48a) extending across interior spaces in said plates.

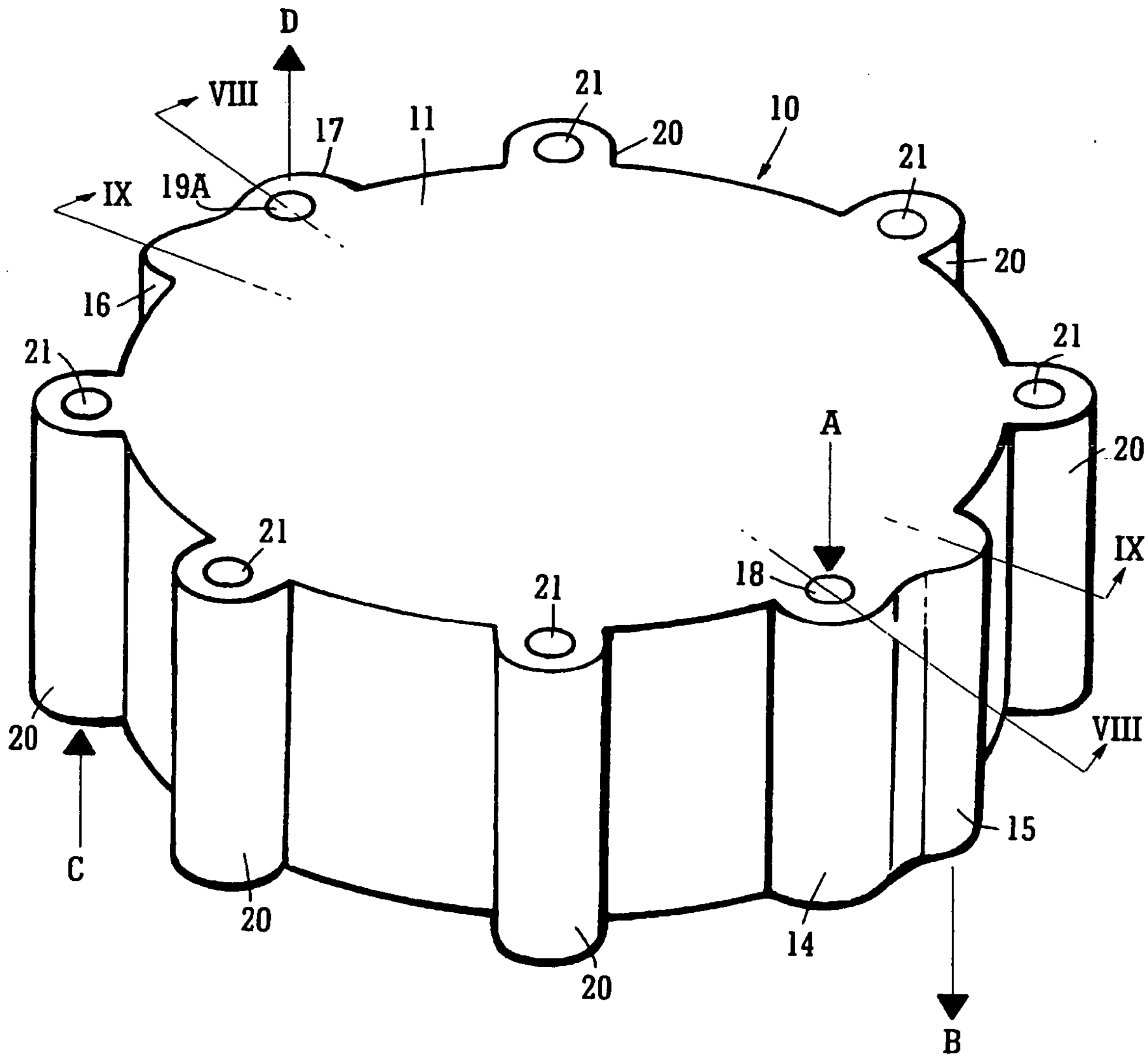
8. A heat exchanger according to Claim 7, wherein the pins (47 47a) of adjacent plates are axially aligned and the ligaments (48, 48a) of adjacent plates are transversely aligned.

9. A heat exchanger according to any preceding claim, wherein the generally annular plates (30, 50, 100) of at least one group have radially outwardly extending barriers (45) interdigitating with radially inwardly extending barriers (44) to define said tortuous flow path.

10. A heat exchanger according to any preceding claim, wherein said generally annular plates (11, 11a, 30, 50, 60, 80, 81, 100) are diffusion-bonded together.

11. A heat exchanger according to any preceding claim, wherein the generally annular plates (30, 50, 100) of the first group alternate with generally annular plates (80, 81, 100) of the second group and said first and second flow paths are similar.

12. A heat exchanger substantially as described hereinabove with reference to Figures 1 to 11 of the accompanying drawings.


D
VIII
17
11
21
20
10
21
IX
19A
20
16
21
21
A
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IX
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18
21
20
VIII
15
C
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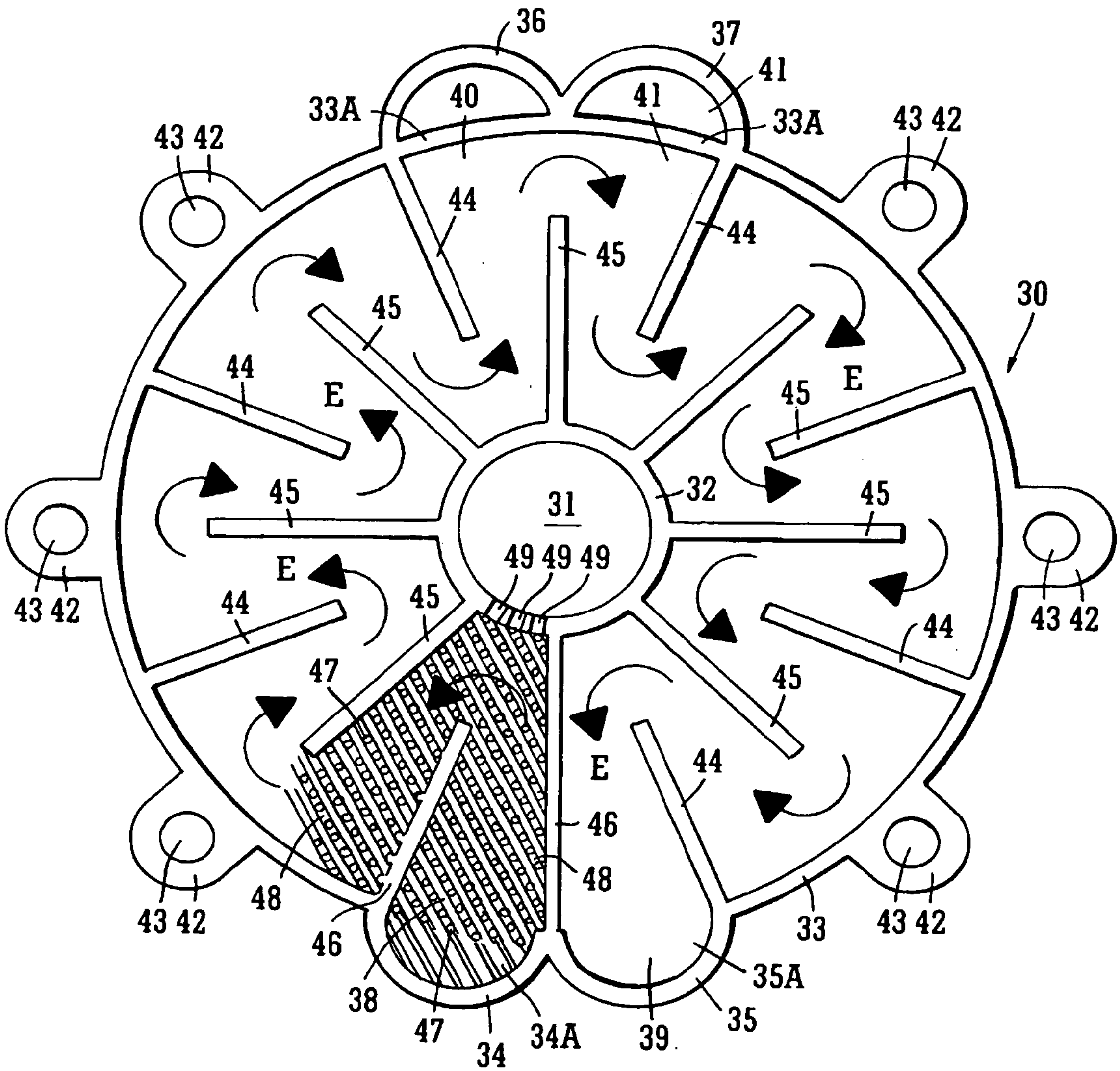
20
14
20
B

FIG. 1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41
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41
33A
33A
43 42
43 42
44
44
45
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45
32
31
45
45
49 49 49
E
43 42
43 42
44
45
44
47
45
E
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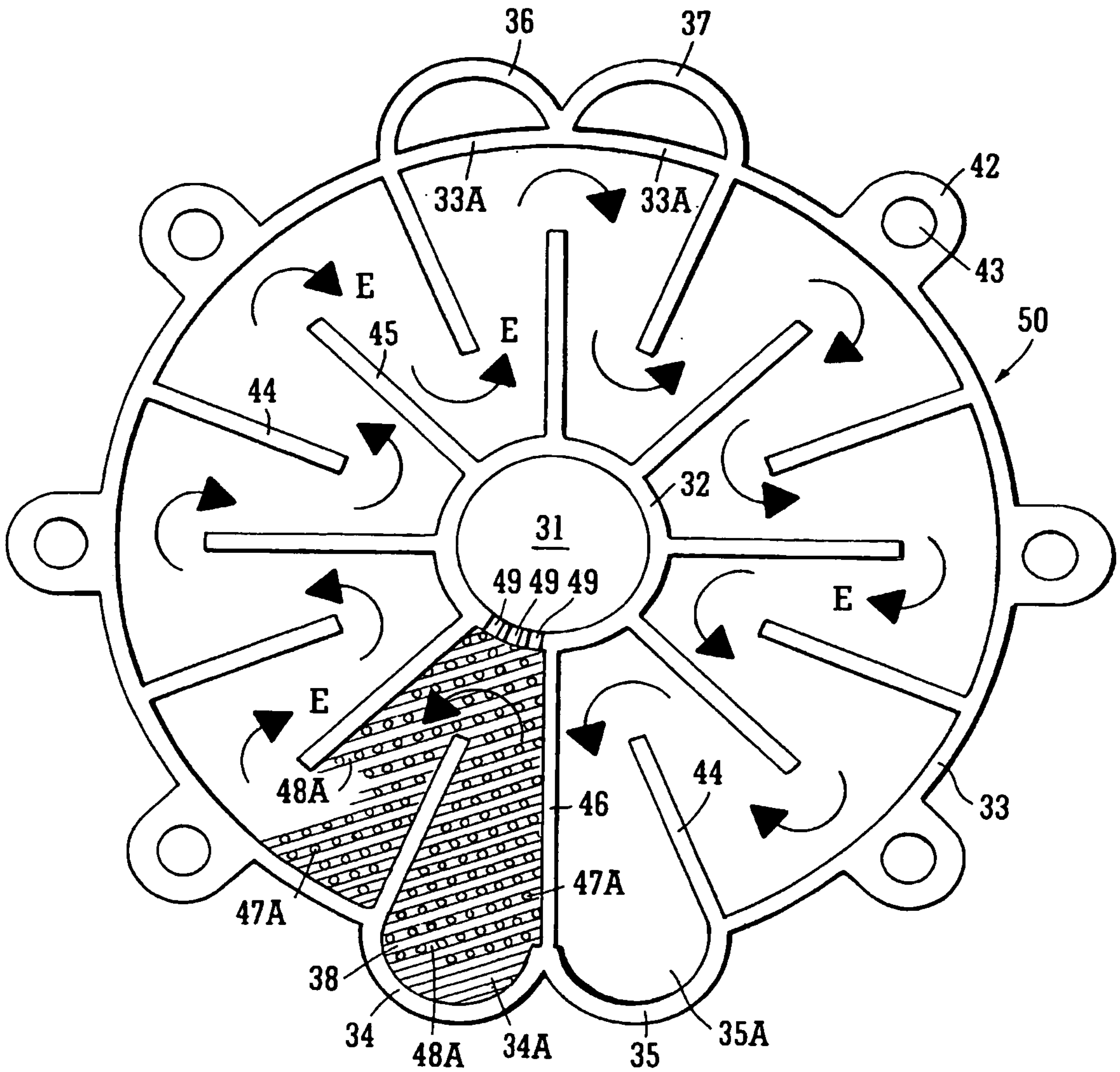
46
48
48
43 42
46
33
43 42
35A
38
35
47
34A
39
34

FIG. 2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31
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47A
47A
38
34
48A
34A
35
35A

FIG. 3

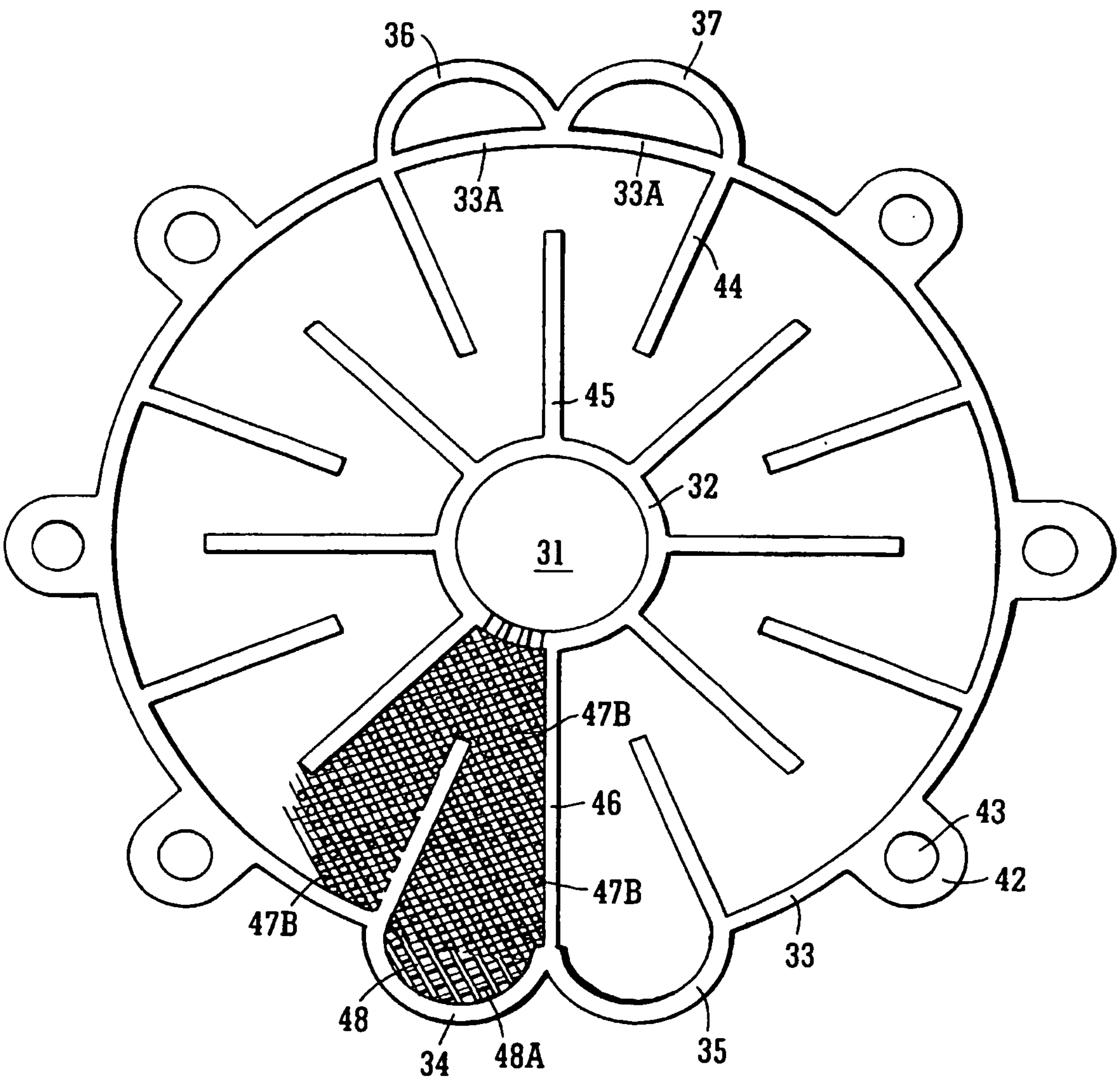


FIG. 4

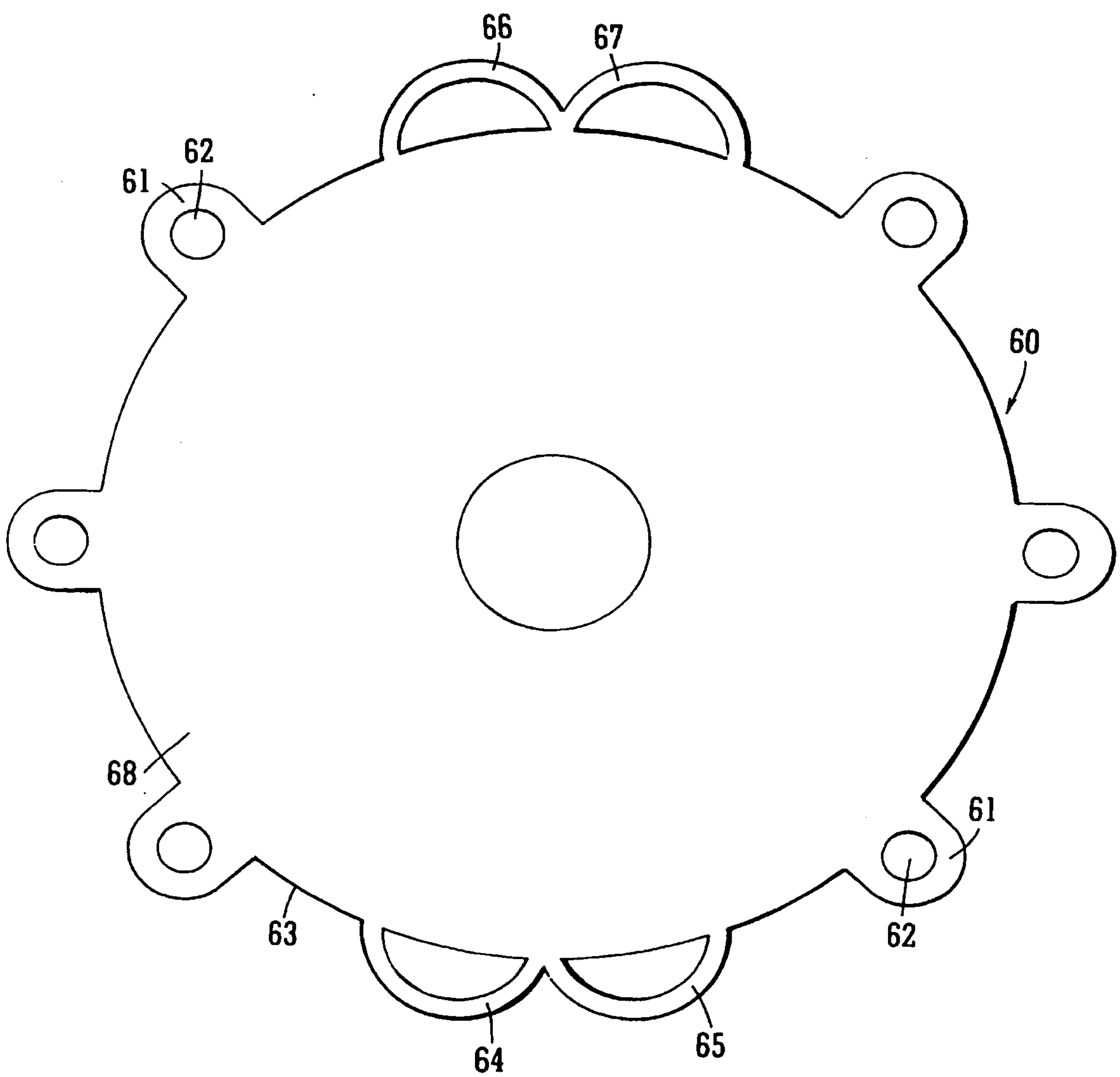


FIG. 5

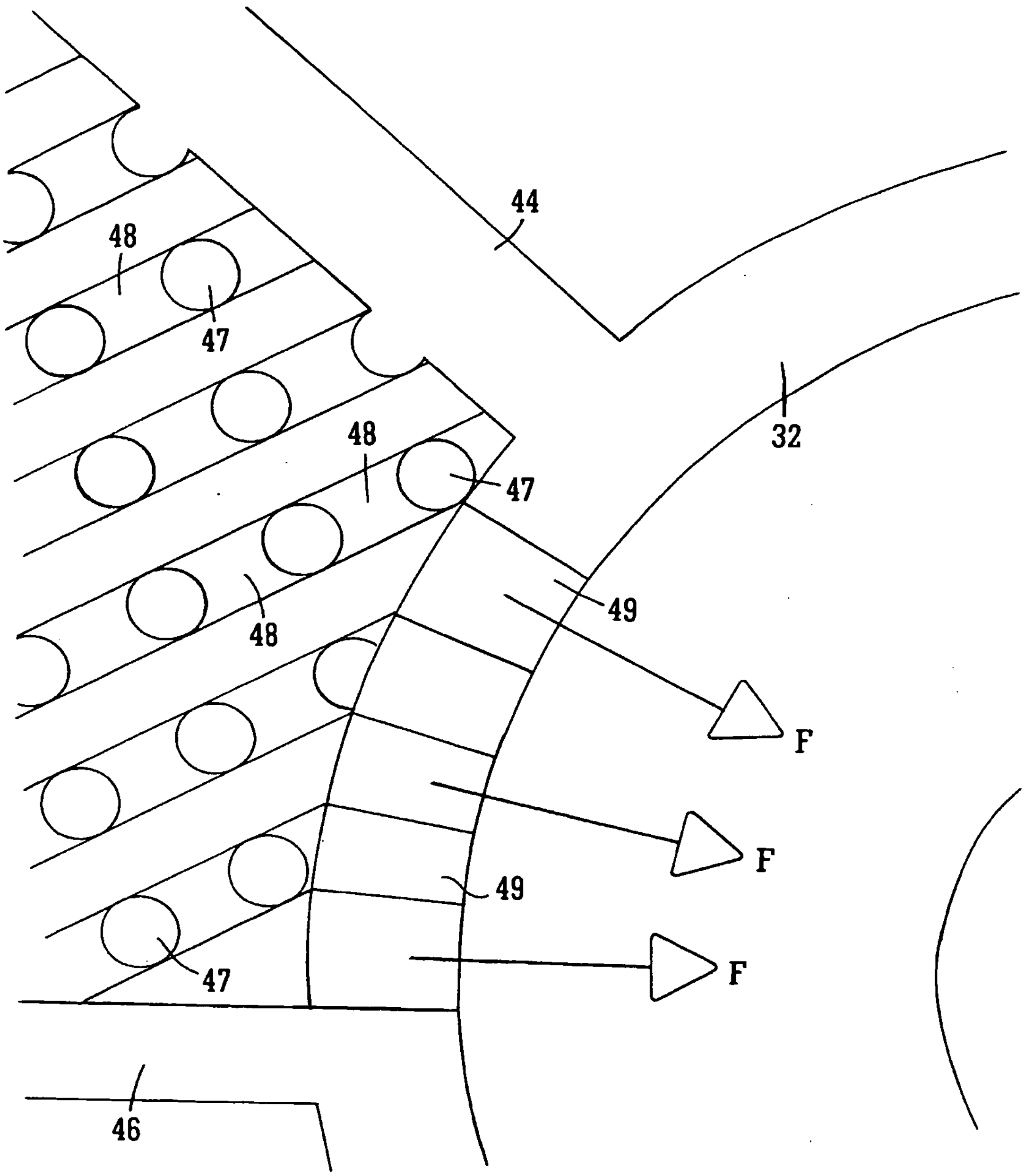


FIG. 6

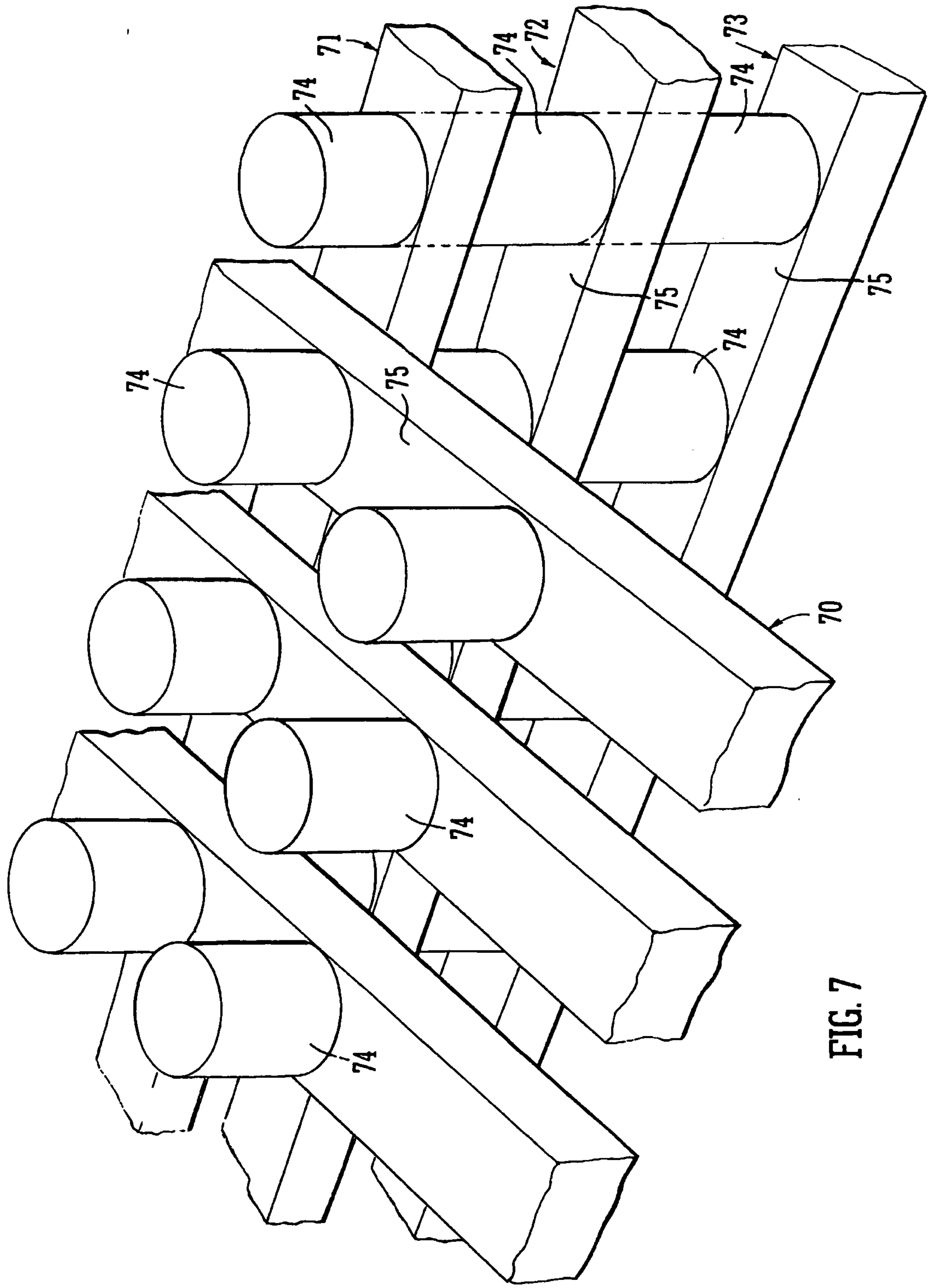
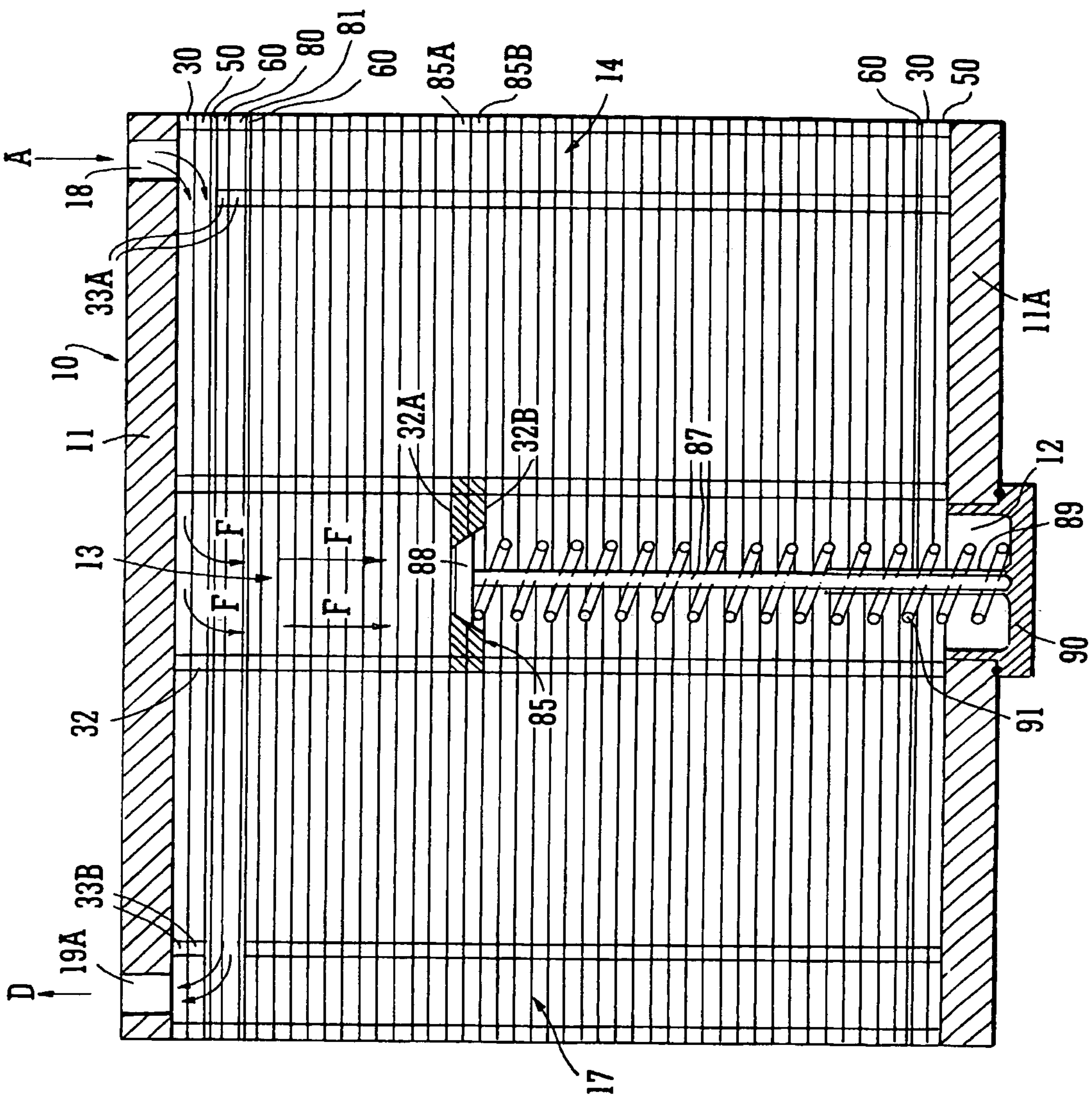


FIG. 7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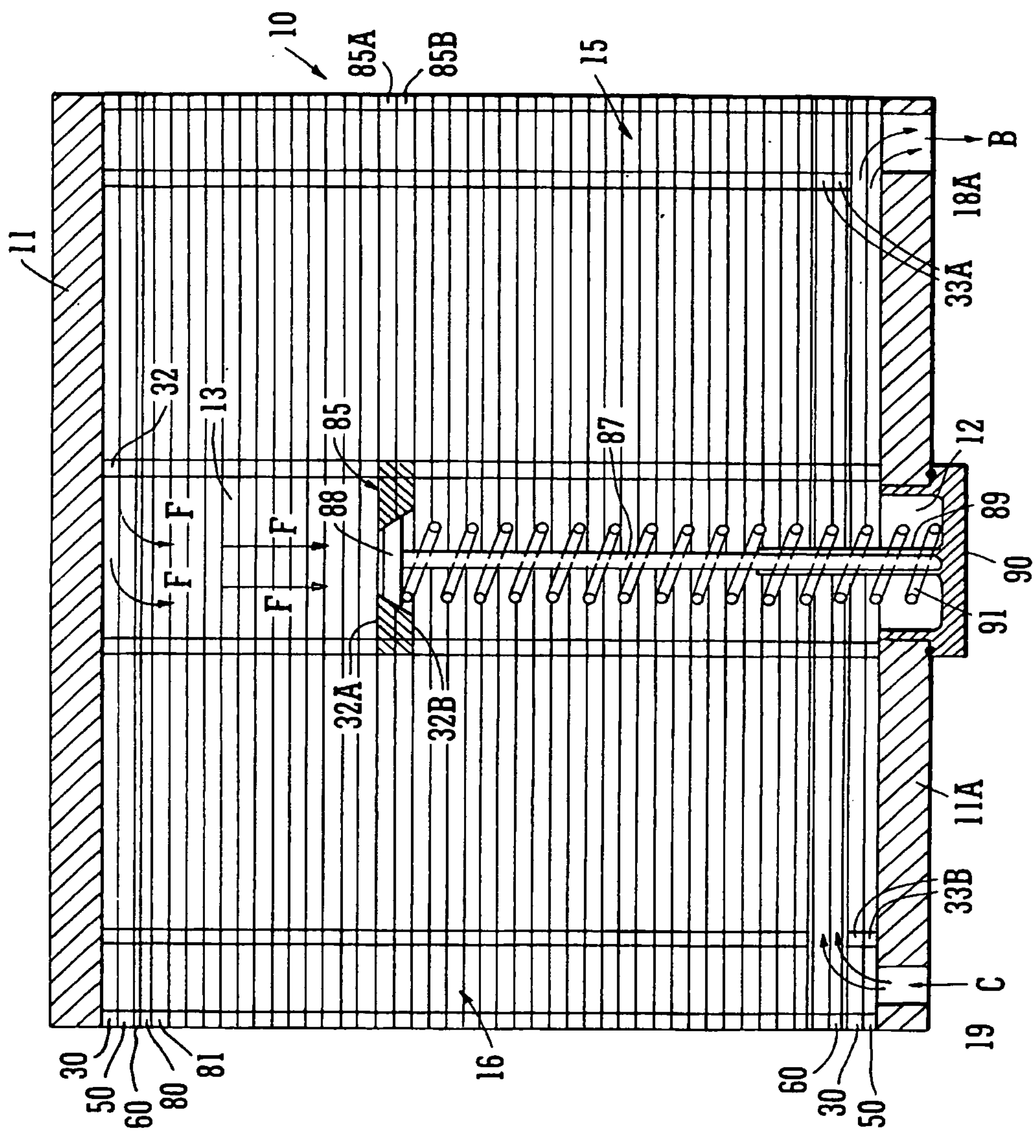
50
60
80
81
60
85A
85B
14
60
30
50
A
18
33A
10
11
11A
32A
32B
87
12
13
F
88
89
90
32
85
91
33B
19A
D
17

FIG. 8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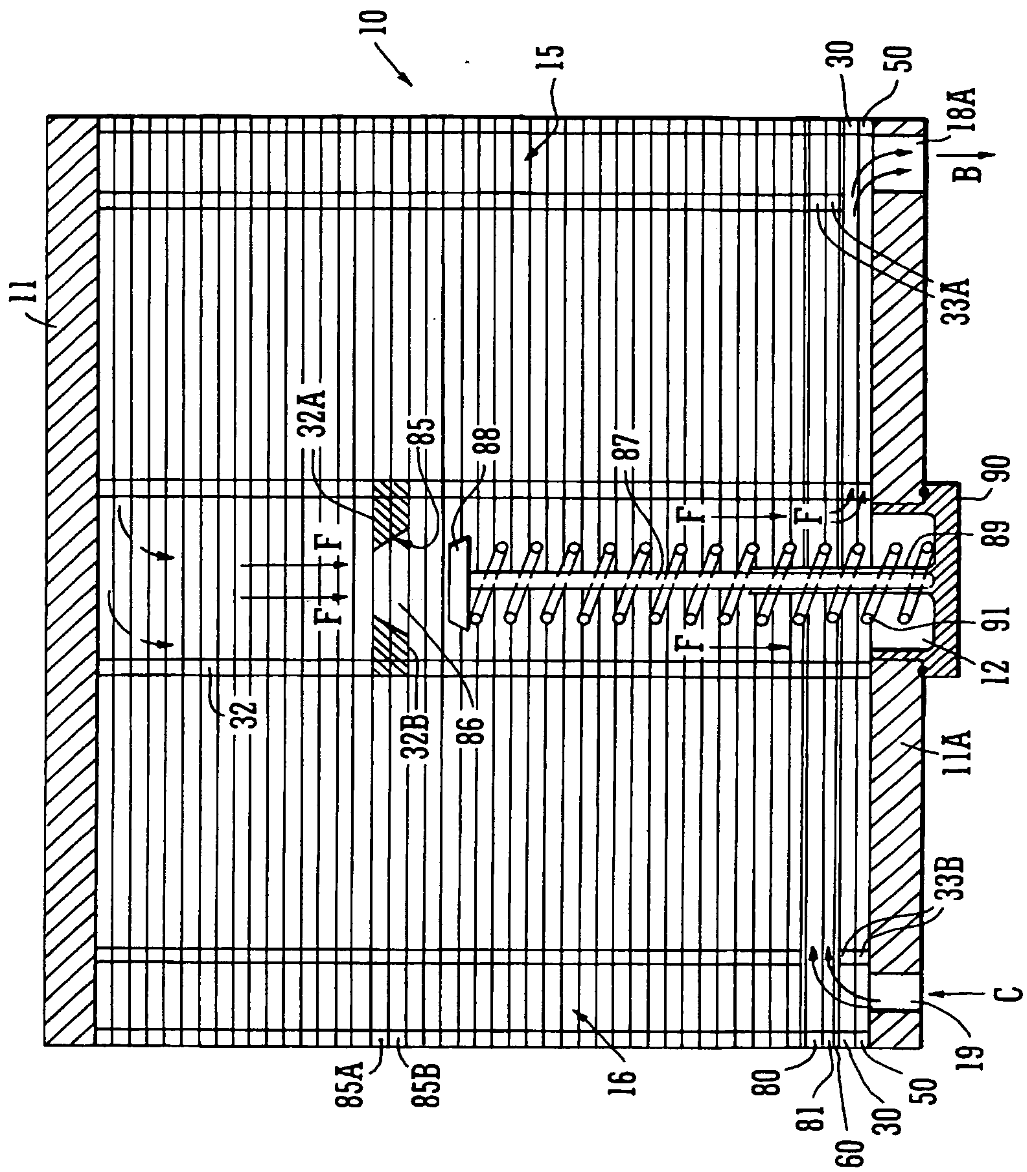
85A
85B
15
11
B
18A
33A
32
13
85
87
12
F
F
F
F
88
89
90
91
32A
32B
11A
33B
C
19
30
50
60
80
81
16
60
30
50

FIG. 9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18A
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33A
32A
85
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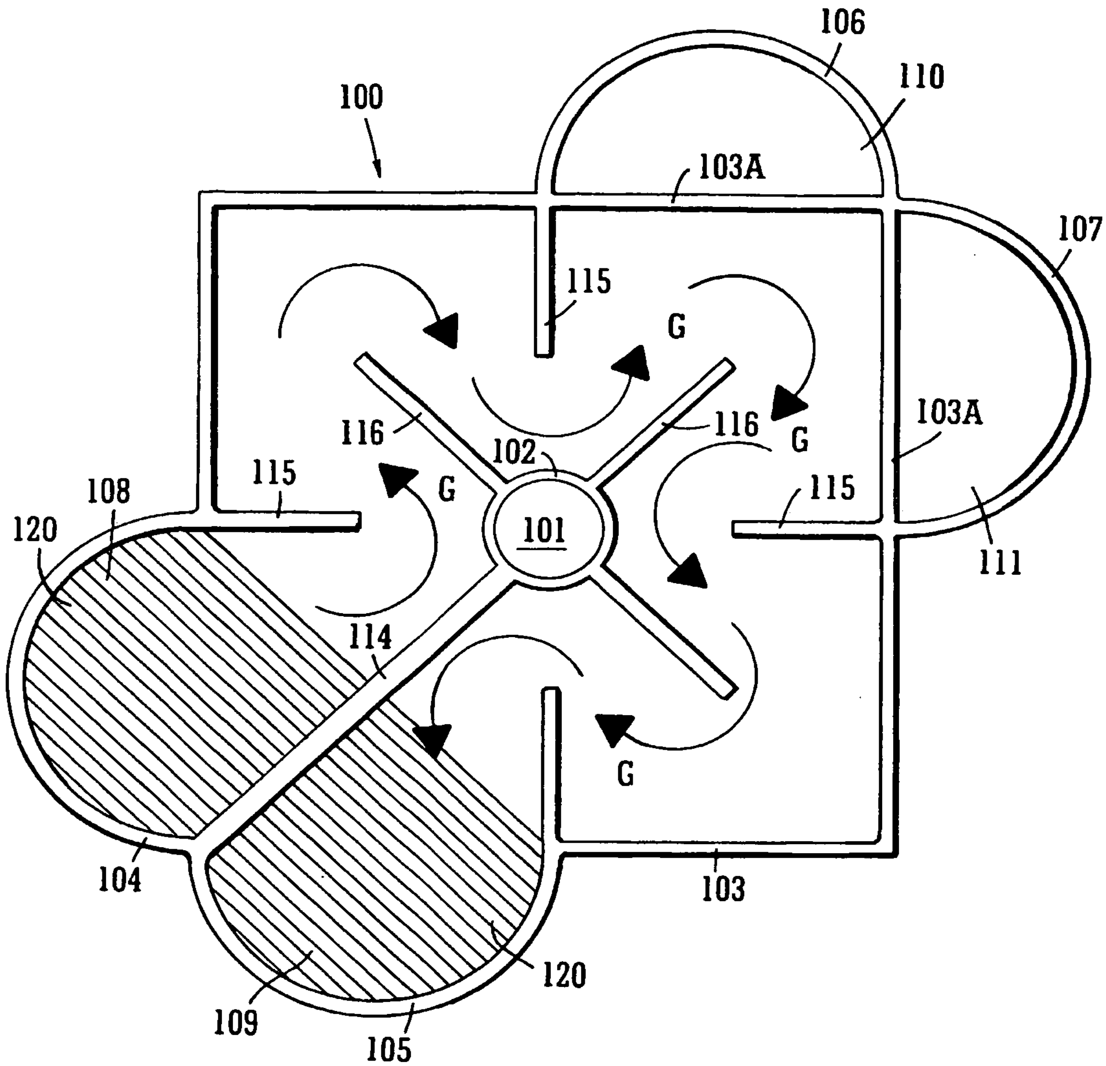
87
F
90
89
91
12
32
32B
86
11A
33B
C
19
85A
85B
16
80
81
60
30
50

FIG. 10



106
110
100
103A
107
115
G
116
116
G
103A
102
115
G
115
108
120
101
111
114
G
104
103
120
109
105

FIG. 11

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 02/02636

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F28D9/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F28D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 20017 A A.D. 1914 (A. J. ERICSON MUNTERS) 2 September 1915 (1915-09-02) the whole document ---	1,9,11, 12
Y	US 3 743 011 A (FROST D) 3 July 1973 (1973-07-03) column 4, line 20 -column 5, line 28; figures ---	1-6,9-12
Y	WO 98 55812 A (CHART MARSTON LIMITED ;SYMONDS STEVEN PAUL (GB); SYMONDS KEITH THO) 10 December 1998 (1998-12-10) cited in the application page 16, paragraph 7 -page 18, paragraph 1; claim 19; figures 7,8 --- -/--	1-6,9-12

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 October 2002	25/10/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Mootz, F

2

Int ional Application No
PCT/GB 02/02636

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99 66280 A (CHART MARSTON LIMITED ;SYMONDS KEITH THOMAS (GB)) 23 December 1999 (1999-12-23) cited in the application claims; figures	7,8
A	DE 78 566 C (MASCHINENFABRIK GREVENBROICH) 17 December 1894 (1894-12-17) the whole document	1-12
A	US 5 014 775 A (WATANABE HIROSHI) 14 May 1991 (1991-05-14) abstract; figures	1-12

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int tional Application No
PCT/GB 02/02636

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
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			EP	1162426 A2	12-12-2001
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			EP	1086349 A1	28-03-2001
			WO	9966280 A1	23-12-1999
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US 5014775	A	14-05-1991	NONE		